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TOPIC n° 2.1: Design and control of automated agricultural vehicles and systems

Search strategies and the automated control of plant diseases

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Abstract: We propose the use of the “infotaxis” search strategy as the navigation system of a robotic platform, able to search and localize infectious foci by detecting the changes in the profile of volatile organic compounds emitted by an infected plant. We builded a simple and cost effective robot platform that substitutes odour sensors in favour of light sensors and study their robustness and performance under non ideal conditions such as the existence of obstacles due to land topology or weeds.

1. Introduction

Plant diseases represent a major economic and environmental problem in agriculture and forestry. Upon infection, a plant develops symptoms that affect different parts of the plant causing a significant agronomic impact. As many such diseases spread in time over the whole crop, a system for early disease detection can aid to mitigate the losses produced by the plant diseases and can further prevent their spread (Sankaran et al., 2010). Moreover, plant diseases are commonly mitigated by the generalized use of chemical pesticides applied over the whole crop, leading to ground and water pollution. Successful techniques for the detection of plant diseases must be fast, reliable, preferentially specific to a particular disease, cost-effective, and sensitive enough for their application at the early onset of the disease symptoms (Lopez et al., 2003).

Current approaches for the detection of plant diseases are divide in two groups, one involving the spectroscopic and imaging techniques and another based on the application of Volatile Organic Compounds (VOC) as possible biomarkers of the presence of disease (Zhan et al., 2010). Here we propose an automated non-destructive methodology based on chemosensing microtechnology and mathematical search algorithms to localize the position of infectious *foci* by detecting the changes in the profile of VOC characteristic of an infected plant.

Odour localization is a major challenge in robotics, mainly because odour plumes consists of turbulent non-uniform patches dispersed by the wind, and several synthetic mathematical algorithms of odour localization have been proposed (Kowadlo & Russell, 2008). We propose the infotaxis search algorithm as the navigation system of a robotic platform. Infotaxis (Vergassola et al., 2007. The use of infotaxis has been recently studied as a navigation system for robots in (Moraud et al., 2010) using temperature sensors and in (Garcia Ramirez et al., 2011) using electronic noses in a controlled environment. Here instead, we propose to avoid the current technical limitations involved in chemical sensing by using optical sensors. We show that, with tools commonly available in any university, a robot platform can be constructed and used to evaluate the robustness of search algorithms under no ideal (laboratory) conditions.

2. Materials and methods

We have designed and built a minimal robot platform to study the performance and robustness of search algorithms under realistic environments.

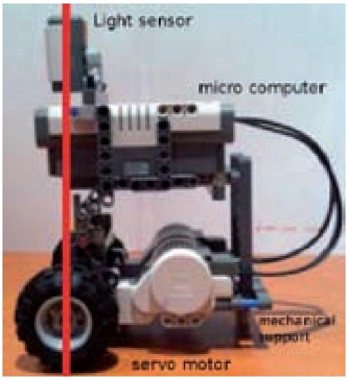

Fig. 1. Minimal design of the robot platform. The vertical line indicates the alignment of the light sensor with axis of rotation.

2.1 Minimal robotic design

A mobile robot was designed using the hardware set of NXT LEGO (http://mindstorms.lego.com/). The robot design, consisted in two servo motors each controlling one wheel. Both wheels were axially aligned and a third fixed mechanical support was placed on the back of the platform. The robot was equipped with one single light sensor pointing upwards. The motors and data acquisition was controlled by one inline NXT micro-computer, programmed in java for LEGO Mindstorms (http://lejos.sourceforge.net/) using the Eclipse IDE.

2.2 Infotaxis algorithm

The infotaxis strategy (Vergassola et al., 2007) assumes that the information comprises molecules that are emitted by the source at a rate γ, and are transported by turbulent air flow, characterized by a mean wind velocity $\boldsymbol{V}$ and diffusion coefficient D. The searcher is assumed to know at any instant of time t and position $\boldsymbol{r}$ the expected probability to make a detection $R(\boldsymbol{r}|\boldsymbol{r_0})$, given that the source is in the position $\boldsymbol{r_0}$. The infotactic searcher starts exploring the space and collects information in terms of the detections or no detections of molecules. Using this information and Bayesian inference, it reconstructs the posterior probability, called belief function, $P_t(\boldsymbol{r_0})$ of the unknown position of the source. Finally, the searcher chooses its next position as that at which the decrease of Von Neumann entropy S is highest, thus maximizing the gain of information at every move.

2.3 Infotaxis as navigation system

To implement the infotaxis algorithm as the robot navigation system we assume that the robot sensors are capable of measuring a finite number k of detections. For simplicity, we assume as well that the robot can only move in four different directions (forward, backward, right or left) with a fixed step length σ, or stands still. This is schematically exemplified in Fig. 2. When the robot is at position $\boldsymbol{r}$ at time t, infotaxis reconstruct the belief function (shown as contour curves in Fig. 2), with associated entropy S. The algorithm then determines the next movement of the robot as that for which the decrease in entropy ΔS is maximal. The robustness of the search is ensured by the exponential decay observed in the distribution of search times. For a discussion of robustness in search strategies we refer the reader (Mejia-Monasterio et al., 2011).

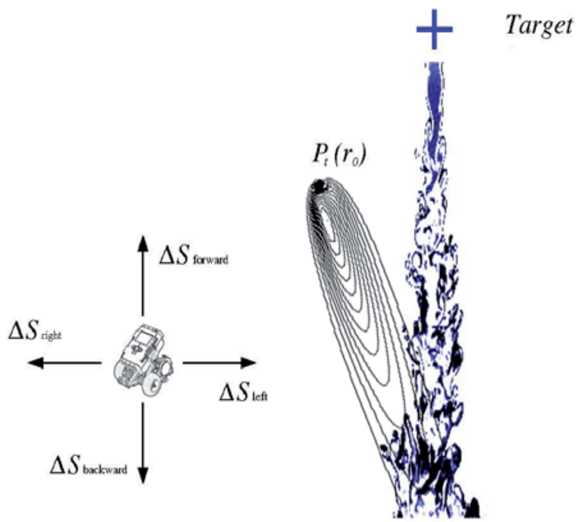

Fig. 2. Schematic representation of the steps involved in the infotaxis algorithm.

3. Results and conclusions

We simulate odour molecules as circular white light spots of radius ρ at a position that is chosen randomly according to the probability $R(\mathbf{r}|\mathbf{r}_0)$. The light spots are vertically projected with a commercial beamer on the ground, covering an area of *1.8* by *2.2* meters in which the robot moves with its light sensor pointed upwards, and last for a time *T*. Several tests were performed to find optimal values for ρ, *T,* and the speed *v* of the robot. The light sensor was then set to record data every *3* ms, with a detection threshold of *450* in absolute units. The number of detections η was obtained as the sensor response integrated during the motion of the robot. The infotaxis algorithm was programed in Fortran 90 language and compiled using the Intel Fortran compiler (http://software.intel.com/). The communication between the NXT processor and the infotaxis algorithm (running on a separate computer) was achieved via the exchange of text files. The NXT sends the number of detections η during its last movement and its direction. Infotaxis use η and the current position of the robot to compute the next movement and sends back two integers θ={-90,0,90,180} and d={0, σ}, to the NXT. The robot rotates θ degrees and move for a distance *d*.

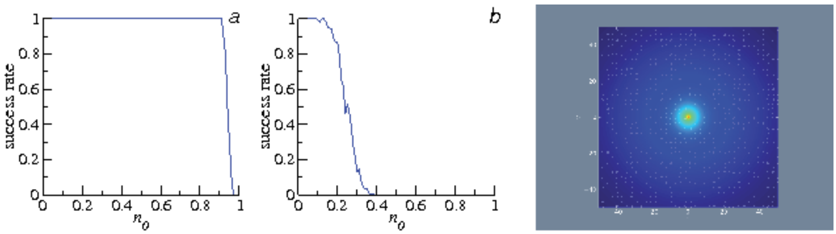

Fig. 3. Panels *a* and *b* show the success rate of the robot trials locating the target as a function of the density of obstacles n_0, when it moves in a triangular and square lattice respectively. The right panel shows the density of lattice sites visited by the robot for a square lattice with obstacles.

We have tested the robot trajectories through numerical simulations and studied the performance of infotaxis in the presence of obstacles placed randomly on square and triangular lattices with density n_0. The results in Fig. 3, show that the search on a triangular geometry is more robust. This is of special relevance since crops under triangular geometries has shown to be more effective in the production of biomass compared to the traditional furrow geometry (Morente et al. 2011). Our results show that infotaxis is a promising strategy for the location of infectious foci in crops. While the technology required to achieve this goal does not exist yet, this study paves the road for future developments and for the optimization of search strategies as a method for early stage control of plant diseases.

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